What we claim as our invention is:

4. A method for automatic handling of bulk material and other goods where this handling comprises loading, unloading and transport executed by a mobile robot such as an autonomous vehicle or machinery, for industrial applications within limited work areas, outdoor as well as indoor or under ground, c h a r a c t e r i s e d b y:

- One or several loading zones are defined for the work area, such loading zones being the sole parts of the work area where loading and working of a volume of material is allowed for collection of material or other objects, and one or several unloading zones being the sole parts of the work area where unloading material and other objects is allowed, and one or several obstacle free zones which together with the loading and unloading zones are the only parts of the work area where autonomous vehicle navigation and autonomously controlled load handling implement movements are allowed;
- A reference surface is defined for the work area as being the supporting surface for material volumes and other handling objects, such a reference surface being accurately defined in a coordinate system fixed to ground by means of the x-, y- and z-coordinates for an ordered set of points on the same reference surface, this surface being compared with current terrain surface measurements including the surface of material volumes and other handling objects located within loading and unloading zones, and where these measurements are used for optimising parameters for vehicle navigation and vehicle load handling implement movements in loading and unloading tasks as well as for obstacle detection;
- The position of the mobile robot is obtained, in real time and outdoor as well as indoor or under ground, by an apparatus for accurate determination of the position in a fixed to ground coordinate system in three dimensions x, y and z and the three attitude angles heading, pitch and roll, in all comprising a position determination in sex degrees of freedom of a fixed to vehicle coordinate system, where such an apparatus can be a laser-optic system in which the position is determined through azimuth and elevation measurements, with an on board the vehicle rotating laser-optic sensor in a fixed to vehicle coordinate system, towards a number of reflectors with known coordinates in the fixed to ground coordinate system;
- The current shape and location of the terrain surface, outdoor as well as indoor or under ground, is determined by estimating, in a fixed to ground coordinate system,

the position in three dimensions of points on this terrain surface, by means of azimuth angle and range measurements in a fixed to vehicle coordinate system by means of at least one scanning laser rangefinder, and coordinate transformation of such measurements into coordinates in the fixed to ground coordinate system using the six degrees of freedom position estimates in the fixed to ground coordinate system of the fixed to vehicle coordinate system by means of the abovementioned position determination;

- The storage, processing and updating operations of the terrain surface shape and location data are made in an on board vehicle dynamic terrain model, where data from this model is used when optimising vehicle paths and load handling implement movements throughout loading and unloading tasks by allowing calculations of pertinent positions and shape elements of material volumes, other handling objects and obstacles, where this model comprises at least three essential layers with for each terrain element n within the work area specific elevation values:
  - Z(1,n) for layer number 1: emerging model based on data from the vehicle's actual pass in its path where this data is obtained from terrain surface measurements,
  - Z(2,n) for layer number 2: best estimate of the reference surface devoid of material volumes, other handling objects and obstacles based on initial measurements of terrain surface inside the work area, measurements made by either the abovementioned method element for terrain surface shape and position estimation or by other means collected information of terrain surface shape and position,
  - Z(3,n) for layer number 3: a current estimate of the entire terrain surface within the work area including material volumes, other handling objects and obstacles, where this dynamic terrain model is analysed in order to 1) optimise the position of the attack point or optimising the bucket unloading position, respectively, as well as 2) optimising the vehicle's position when attacking for loading or when unloading the bucket, respectively, and 3) for estimating a terrain height profile along the intended loading path of the bucket giving, for each one of a number of successive penetration depths $s_g(i)$, i = 0, 1, 2,... of e.g. the forward tip of the bucket yielding an average level $Z_{loading}(i)$ in a fixed

to ground coordinate system for the material volume in a neighbourhood of the forward edge of the bucket;

- An on board mission computer is employed where this computer is provided with mission instructions defining obstacle free zones, loading and unloading zones, parameters for static and dynamic transport paths, reconnaissance paths, loading and unloading paths including also programs contained in the mission instructions for selecting and tying together a sequence of paths and movement processes in order to assemble one or several handling cycles, and furthermore provided with algorithms for vehicle path optimisation and vehicle and load handling implement movements when loading and unloading based on attack point coordinates and bucket unloading point, respectively, plus the terrain height profile $\{Z_{loading}(i), s_g(i), i = 0, 1, 2,...\}$ from the dynamic terrain model;
- An on board vehicle control computer is employed for controlling vehicle and load handling implement in the current vehicle path and the current vehicle and load handling implement movement process based on data from the mission computer, where this vehicle control computer has interfaces to the actuators and sensors intended for the steering and driving of the vehicle and its load handling implements.

5. A method according to claim **4** for obstacle detection for the purpose of avoiding the vehicle to get into a too close proximity of or colliding with an obstacle, to supervise the progress of the vehicle in order to initiate an emergency action should the vehicle risk to move outside the areas intended for autonomous navigation and in order to evaluate and accept or reject planned vehicle paths and vehicle and load handling implement movements, by employing the dynamic terrain model for this purpose and characterised by:

- An additional layer in the dynamic terrain model is used for marking obstacle free terrain elements;
- Classifying an element no n in the dynamic terrain model as an obstacle free or not obstacle free terrain element is done by continuously comparing Z(1,n) of the emerging model layer of the dynamic terrain model with the current best estimate if the terrain surface Z(3,n), whereby the element no n shall be classified as

obstacle free if $[Z(1,n) - Z(3,n)] < H$, where H is a given least obstacle height for not classifying an element as obstacle free,

- Evaluating and accepting or rejecting planned paths and considering the risk of the vehicle moving outside those areas intended for autonomous navigation, for the purpose of being able to detect possible planning errors prior to driving an intended path, this evaluation is made by testing for each element no n in the dynamic terrain model if such an element to any part contains a part of an obstacle avoidance zone mapping for any one of the successive positions of the vehicle in the planned path, whereby, if such a terrain element does not belong to any loading, unloading or obstacle free zone, the planned path will be rejected, where: One or more obstacle avoidance zones are defined in a fixed to vehicle coordinate system;
    - ❖ A specific obstacle avoidance action can be assigned to one or more obstacle avoidance zones;
    - ❖ Obstacle avoidance zone projection is a for the moment defined surface in the fixed to ground coordinate system, where such a surface is the horizontal projection of a fixed to vehicle obstacle avoidance zone for a specific vehicle position in its path;
    - ❖ Obstacle avoidance zone mapping in the fixed to ground coordinate system is the union set of a sequence of all obstacle avoidance zone projections, where each such projection corresponds to a specific position of a sequence of positions of the vehicle in its path;
- Obstacle avoidance action is initiated based on the presence of a non obstacle free element no n in the dynamic terrain model inside any obstacle avoidance zone projection for the present position of the vehicle, in which case the obstacle avoidance actions carried out are assigned to the corresponding obstacle avoidance zone;
- Obstacle avoidance action is also initiated on the presence of a non obstacle free element no n of the dynamic terrain model inside any obstacle avoidance zone mapping representing the planned path of the vehicle, whereby the obstacle avoidance actions to be carried out are assigned to the corresponding obstacle avoidance zones.

6. A method according to claim **4** for a vehicle in motion to find a point (X_{load},Y_{load}) or (X_{unload},Y_{unload}) in the fixed to ground coordinate system for the initial position of its load handling implement in a loading or unloading movement, respectively, in a volume of material or other handling objects and where this method employs a dynamic terrain model and is characterised by:

- The vehicle is driven along an in advance planned reconnaissance path towards one inside a limiting polygon defined loading or unloading zone;
- The most suitable point (X_{load},Y_{load}) for attacking the material volume when loading is selected among the elements of the emerging layer Z(1,n) of the dynamic terrain model being most near a given initial line or point or otherwise most optimal, and where the surface of those elements have been determined with a sufficient number of measurements during the vehicle's approach along the reconnaissance path from a point where 1) the value [Z(1,n) - Z(2,n)] of a first element no n of the dynamic terrain model has been determined with a sufficient number of measurements and 2) when the inequality condition A $\leq$ [Z(1,n) - Z(2,n)] is satisfied, where A is a given least height of the terrain surface above the reference surface, till the vehicle from this point has travelled a given further distance along the reconnaissance path;
- Furthermore in a loading task this aforementioned search, for nearest or otherwise most suitable attack point (X_{load},Y_{load}) for the vehicle's loading bucket or other implement, is confined to such elements no n of the dynamic terrain model for which a condition B $\leq$ [Z(1,n) - Z(2,n)] is valid, where B is a given least feasible loading level above the reference surface per element;
- In an unloading task the search within the unloading zone for most remote or in another way most suitable unloading point (X_{unload},Y_{unload}) for the vehicle's bucket or other implement is confined to such elements of the dynamic terrain model for which the inequality [Z(1,n) – Z(2,n)] $\leq$ C is valid, where C is a given maximum height above the reference surface for an element for allowing unloading on this element.

7. A method according to claim **6** to fill a bucket in an automatic loading operation based on the information of a material volume derived from a dynamic terrain model and where the planning and optimisation of parameters for vehicle and load handling implement movements is c h a r a c t e r i s e d b y:
   - Parameters for the loading path of the vehicle and the lift and tilt movements of the load handling implement are determined during the vehicle's movement along an approach path between the first detection of a material volume and the arrival to the attack point by employing a terrain height profile table, which is based on actual terrain according to the emerging layer Z(1,n) of the dynamic terrain model for a number of points no i = 0,1,2,3,..., with corresponding penetration depths $s_g(i)$ along the planned path of the loading bucket, and where the Z coordinate $Z_{loading}(i)$ for each such point no i represents, in a fixed to ground coordinate system, an average value of Z(1,n) for elements number n located in a specific proximity of the front edge of the bucket;
   - The volume to become loaded is calculated as the volume that will be cut out by the bucket for a sequence of its positions k = 0,1,2,3,... in the same fixed to ground coordinate system, according to the model for planning the vehicle and its load handling implement movements, and from which is obtained an estimate of how deep into the material volume the bucket must be penetrating during the loading process, and also when lift and tilt movements shall be commenced and terminated during the final phase of the loading operation.

8. A method according to claim **7** for minimising the friction caused by the support reaction force on the bucket when the bucket is moved towards and into a material volume, c h a r a c t e r i s e d b y:
   - Minimising the friction is done by controlling a hydraulic pressure to the lift cylinders of the load handling implement, where the control parameters are optimised in a model based on an estimate of, and in order to balance the total weight and moment of the load handling implement with bucket and its expected loaded volume as a function of penetration depth s(k), k= 0,1,2,3,..., and the lift and tilt movement process of the load handling implement and by employing the height profile table $Z_{loading}(i)$, i = 0,1,2,3,..., from the dynamic terrain model.